X-Ray Production in Super Nova Remnants

N64-18431 *

CODE-1

G. W. Clark and M. Oda* [1963] 7p

Laboratory for Nuclear Science
Massachusetts Institute of Technology
Cambridge, Massachusetts

NsG-386

(NASA CR-53591)

UNPUBLISHED PRELIMINARY DATA

The most prominent feature of galactic x-rays, which have been studied in three separate rocket experiments by Giacconi et al[1] [2] and also by Friedman[3], is a pronounced anisotropy that indicates the existence of a concentrated source in the constellation Scorpius. The angular diameter of the source appears to be less than 10^{o}, and its direction is close to but definitely not coincident with the galactic center (g.c.). The energy range of x-rays observed is about 1 10 kev and the flux is about $20/cm^2$ sec[1]. From these figures one finds that the x-ray power of the source is about

$$10^{-6} R^2 \quad erg/sec ,$$

where R is the distance in cm. If the source is as far away as the g.c., namely R 3 x 10^{22} cm, its power is 10^{39} erg/sec which is more than 10^5 times the total luminous power of the sun. Such an enormous x-ray power is difficult to explain by any of the mechanisms proposed thus far if they must operate steadily outside of the g.c. .

For example, inverse Compton collisions between electrons with energies near 20 Mev and starlight photons produce recoil x-rays with energies near 3 kev. The rate of x-ray generation per electron is about 4 x 10^{-23} erg/sec, assuming an energy density of starlight equal to 1 e.v./c.c. .

* On leave of absence from the Institute for Nuclear Study, University of Tokyo.

OTS PRICE

XEROX $ 1.10 ph

MICROFILM $ 0.80 mf.

(NASA Grant NsG-386; Contract AT(30-1)-2098)

The number of electrons required in the source is then $2.5 \times 10^{16} R^2$ or 2.5×10^{61} for a distance of $R = 3 \times 10^{22}$ cm, and the total energy of electrons of this energy range is $2.5 \times 10^{61} \times 20$ Mev $\approx 5 \times 10^{68}$ e.v.

Another possible mechanism for x-ray production is bremsstrahlung from collisons between electrons of several kev and interstellar matter. An electron of several kev radiates x-rays at a rate of 10^{-24} erg/sec, assuming a density of interstellar hydrogen of 10^{-24} g/cm^3. The total number of electrons required is therefore $10^{18} R^2$ or 10^{63} for $R = 3 \times 10^{22}$ cm, and their total energy is $10^{63} \times 3$ kev $\approx 3 \times 10^{66}$ ev. These energies are 10^4 to 10^6 times larger than the total energy released by a super nova which is considered to be the most energetic stellar phenomena.

It is, therefore, quite natural to consider the possibility that the source lies at a relatively short distance away and has a correspondingly reduced x-ray power*. Specifically, we suggest that the source is a super nova remnant at a distance of about 30 l.y. with a spectrum of electrons that is steep compared with that which is presumed to exists in the remnants that have been observed at radio frequencies. It is generally considered that high energy electrons exist in the super nova remnant, being produced either as decay products of nuclear collisions of high energy nucleons and gas, or being accelerated in the hydromagnetic turbulence of the remnant during its early phase. These electrons radiate synchrotron radiation in the magnetic field of the remnant. The radiation is observed at frequencies ranging from radio to optical depending on the energy range of the electrons. The typical properties of the remnants that have been observed are:

1) total energy carried by electrons is $\approx 10^{49}$ erg.
2) energy spectrum of electrons may be represented as $E^{-m}\,dE$, with $m = 2 \sim 3$.
3) dissipation of energy by synchrotron emission and diffusion occur during $10^{3\sim4}$ years.

---

* Hayakawa has also considered possible nearby sources such as neutron stars and binary stars accompained by early-type stars.

It seems reasonable to suppose, however, that the energy spectrum of the electrons in a super nova remnant may have various forms according to the initial conditions of the nova and its environment in interstellar space. The exponent of the spectrum may reflect the efficiency of the acceleration of the particles, and the lower energy part of the spectrum may be mainly determined by whether or not the electrons in the remnant are the decay products of nuclear interactions of protons. For our rough estimates we shall represent the energy spectrum of the electrons by a power law with a low energy cut-off. If this cut-off is below 10 Mev, and if either the total number or the total energy is fixed, then the synchrotron power that is emitted in the observable radio region decreases rapidly with an increase in the exponent of the spectrum. If the exponent is large, then the remnant is not observable by radio-waves. And it is easily understandable that there is not a variety of exponents among actually observed remnants, since those with large exponents are not observed. Thus, there may be a number of super nova remnants which have escaped observation because of their steep spectra. In particular, the remnant of the great AD 1006 super nova which has been discussed by Shklovsky on the basis of ancient oriental chronicles, has not been identified with a radio source.

By way of an example we calculated the spectrum of the electromagnetic radiation that would be produced by electrons with a specific energy spectrum as they undergo synchrotron emission, inverse Compton collisions with starlight and radiative collisions (bremsstrahlung). We assumed a differential spectrum in the form of a power law with an exponent of -7 and with a low energy cut-off of 10 Mev. For the conditions in the remnant we assumed a magnetic intensity of 10^{-5} gauss, a starlight energy density of 10 ev cm^{-3} and a proton density of 1 cm^{-3}. Under these assumptions it turns out that a remnant within 30 l.y. with a total electron energy of 10^{50} erg could produce a sufficient amount of x-rays to explain the observation either by the Compton effect or by bremsstrahlung. The production spectrum for this example is shown in Figure 1 where we have plotted the power emitted per unit volume per unit frequency interval and per unit electron energy density. It also turns out with this choice of parameters that the remnant would not be detectable by radio at 100 mc.

The source may have evolved as follows. After the explosion of the super nova high energy electrons were injected into the interstellar plasma in which the magnetic field is anchored. Since these electrons form an expanding diamagnetic cloud, the magnetic field and, hence, the plasma are expelled[(4)] thereby generating a spherical shock wave. In this way, a spherical cavity is formed in which the electrons are contained and bounce around causing the expansion of the cavity. The velocity of the expansion is the velocity of the shock which is of the order of 300 km/s. In order to be compatible with the observation that the extension of the source is at most 10°, assuming that the distance is 30 l.y., the longest time that may have passed is 2×10^{12} sec or about 10^5 years. It seems likely, however, that it may be shorter.

If the above interpretation of the observed x-ray source is correct, this source could also be a strong source of bremsstrahlung γ-rays with energies near 10 Mev. The number flux could be as much as 10% of the flux of x-rays. It appears possible to argue that the gas may have been totally ionized by the radiation of the super nova and pushed away during the hydro-magnetic expansion leaving no gas in the cavity so that the electrons may not make bremsstrahlung. The characteric time of recombination, however, is of the order of a thousand years and a substantial portion of the gas would have been neutralized before the shock wave or the wall of the cavity passes. Therefore, a substantial amount of gas is probably still contained in the cavity.

Another possibility that may be worth consideration is that the source is a remnant in the very early phase of a relatively distant super nova obscured by a dust cloud. It is not seen by radio because the energy spectrum of its electrons is too steep, but it may now be generating x-rays with an intensity that is larger by several orders of magnitudes than at a later phase because the densities of matter and light energy in a very young remnant are certainly much greater than the values quoted earlier. This intense x-ray phase may last only for a few years.

Several observational tests of these ideas are possible. If the source is an old nearby remnant , its x-ray spectrum should extend well into the long wavelength region around 30 Å where interstellar absorption should cut off a distant source. If the source is a distant and recent super nova remnant, it should show a measurable decline in its intensity within a year or so.

REFERENCES

1) Giacconi, R., H. Gursky, F. Paolini and B. Rossi, Phys. Rev. Letters, 9, 439 (1962).

2) Gursky, H., R. Giacconi, F. Paolini and B. Rossi, Phys. Rev. Letters, 11, 530 (1963).

3) Friedman, H., Cospar Conference (June 1963).

4) Oda, M. and H. Hasegawa, Physics Letters, 1, 239 (1962).

Acknowledgements

This work is supported in part through funds provide by AEC contract AT(30-1)-2098 and NASA grant NsG386.

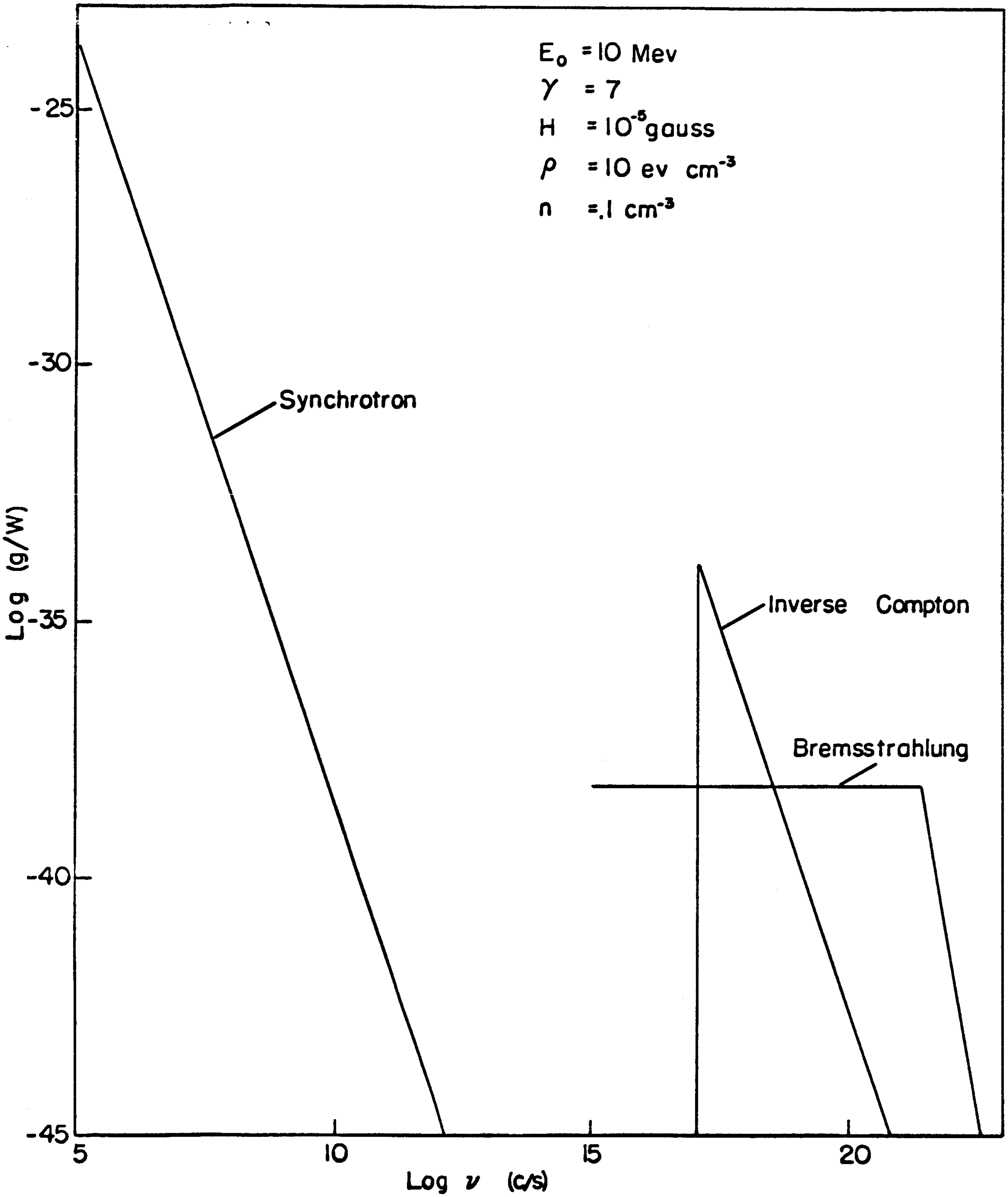
FIGURE CAPTION

Figure 1. The spectrum of electro magnetic radiation produced by electrons with a power law energy spectrum in a region containing a magnetic field, starlight and hydrogen. The assumed spectrum was

$$N(E)dE = \frac{(\gamma-2)W}{E_o^2}\left(\frac{E_o}{E}\right)^{\gamma} dE \quad , \quad E_o < E < E_{max}$$

$$= 0 \quad , \quad E_o > E > E_{max}$$

with $\gamma = 7$ $E_o = 10^6$ ev and $E_{max} = 10^{11}$ ev. The other assumed quantities were magnetic intensity $H = 10^{-5}$ gauss, starlight energy density $\rho = 10$ ev cm^{-3}, starlight photon energy $\epsilon = 1.4$ ev, and gas density $n = 0.1$ atom cm^{-3}. The ordinate is the dimensionless quantity (power generated per unit volume per unit frequency interval) $\div$ (electron energy density).



E_o = 10 Mev
γ = 7
H = 10^{-5} gauss
ρ = 10 ev cm^{-3}
n = .1 cm^{-3}
Synchrotron
Inverse Compton
Bremsstrahlung
-25
-30
-35
-40
-45
Log (g/W)
5
10
15
20
Log ν (c/s)